電気材料技術雑誌 第14巻第2号
J.Soc.Elect.Mat.Eng. Vol.14, No.2, 2005

Optical Limiting Properties in One-Dimensional Photonic Crystal Containing Conducting Polymer as a Defect Layer

Jun Matsumoto[1], Ryotaro Ozaki[1], Akihiko Fujii[1], Katsumi Yoshino[1,2], and Masanori Ozaki[1]

1. Department of Electronic Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamada-Oka, Suita, Osaka 565-0871, Japan

Tell: +81-6-6879-7759, Fax: +81-6-6879-7774

E-mail: jmatsumoto@ele.eng.osaka-u.ac.jp

2. Center for University-Industry Cooperation, Shimane University, Matsue, Shimane 690-0816, Japan

Introduction

Photonic crystal (PC) having an ordered structure with a periodicity of optical wavelength has attracted considerable attention from both fundamental and practical points of view, because in such materials, a photonic band gap (PBG) exists in which the existence of a certain energy range of photons is forbidden.[1,2] Using this novel concept, considerable advance in optoelectronic devices such as nonthreshold lasers and microscopic optical circuits, should be expected. Although one-dimensional (1-D) PC dose not have a complete PBG, there are many applications using extraordinary dispersion of the photon and localized photonic state in a defect layer. Many studies on 1-D PC applications have been reported: air-bridge microcavities,[3] the photonic band-edge laser,[4-6] the nonlinear optical diode,[7] and the enhancement of optical nonlinearity.[8,9]

In this study, we introduced conducting polymer with extended π-conjugation in their main chains expected to possess large third-order optical susceptibility in a dielectric multilayer structure as a defect in a 1-D PC. And we examined optical limiting properties using nonlinear optical effect of conducting polymer.

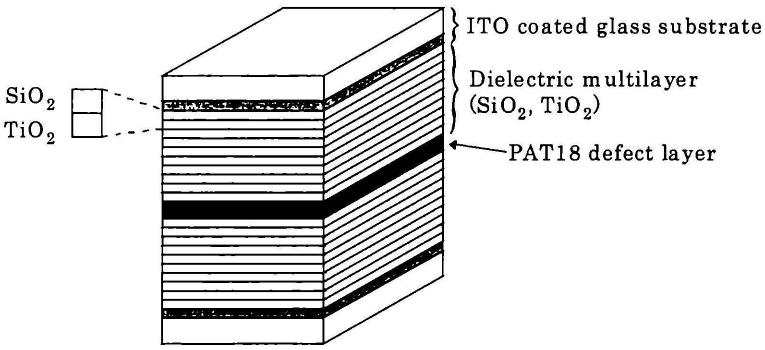

Fig. 1. One-dimensional PC with a PAT18 defect layer.

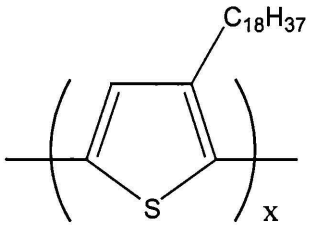

Fig. 2. Molecular structure of PAT18.

Experimental

The 1-D PC with a conducting polymer defect layer is shown in Fig. 1. A dielectric multilayer consisting of an alternating stack of SiO_2 and TiO_2 layers deposited on an In-Sn-Oxide (ITO)-coated glass substrate is used as the 1-D PC. The refractive indices of SiO_2 and TiO_2 are 1.46 and 2.35, respectively, and thicknesses of SiO_2 and TiO_2 layers are 137 and 85 nm, respectively. The number of SiO_2-TiO_2 pairs on each substrate is 5. We used the conducting polymer poly(3-octadecylthiophene) (PAT18) as a defect layer. Molecular structure of PAT18 is shown in Fig. 2. In order to introduce the defect layer, PAT18 was spin-coated on the top surface of the dielectric multilayer and sandwiched between substrates with a dielectric multilayer. The thickness of the PAT18 layer is 470 nm. Then heated in vacuum to melt and bond PAT18.

Figure 3 shows the transmission spectra of 1-D PC with PAT18 defect layer. PBG is observed in the spectral range from 700 nm to 900 nm. One transmission peak is observed at the wavelength of 800 nm, which is based on the defect mode in 1-D PC with a defect layer. The wavelength of the defect mode is 800 nm.

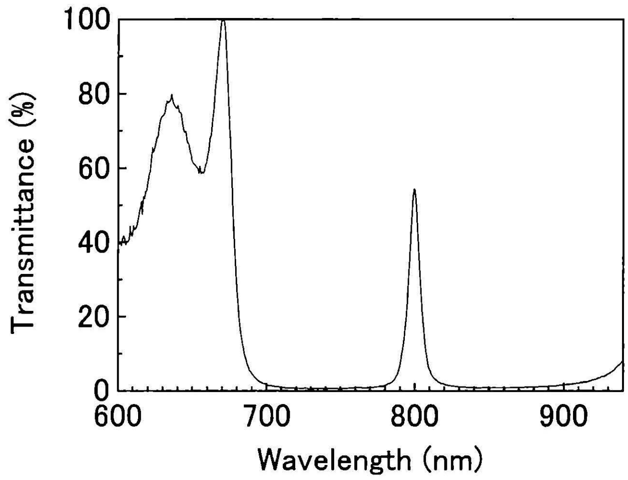

Fig. 3. Transmission spectra of 1-D PC with PAT18 defect layer.

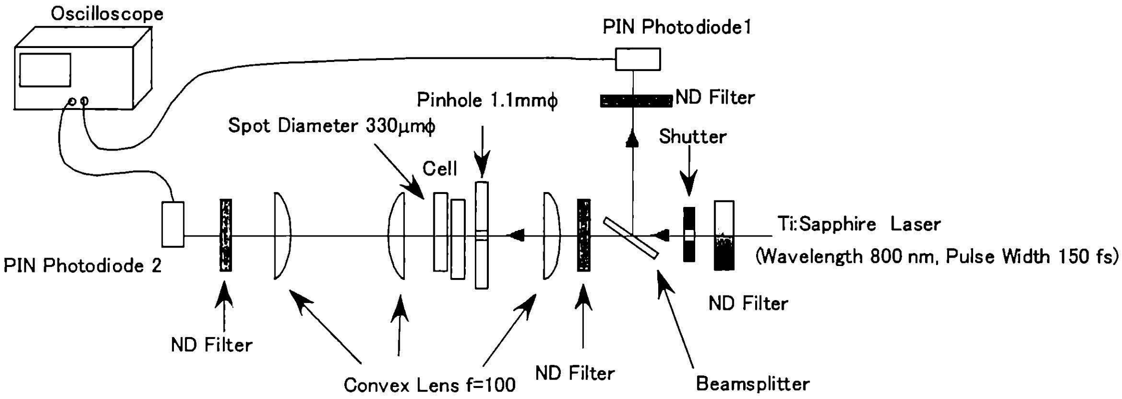

Fig. 4. Experimental setup for measurement of optical limiting properties.

Figure 4 shows an experimental setup for measurement of optical limiting properties. Ti:Sapphire laser (Spectra Physics) whose wavelength, pulse width, and pulse repetition frequency are 800 nm, 150 fs and 1 kHz, respectively is used for measurement of the dependence of transmitted light intensity on the incident light intensity. The wavelength of defect mode of 1-D PC with PAT18 defect layer is corresponded to the wavelength of Ti:Sapphire laser.

Results and Discussion

Figure 5 shows the incident light intensity dependence of the transmitted light intensity of 1-D PC with PAT18 defect layer. Calculation result also depicted in Fig. 5. Till the intensity of incident light below 5 μJ/pulse, the transmitted light intensity increased linearly with the incident light intensity, and above the incident light intensity of 5 μJ/pulse, the increase of the transmitted light intensity was not linear. The calculated result is good agreement with the experimental result. So the optical limiting property was obtained. This optical limiting property is because that the nonlinear refractive index effect appears with the increase of the incident light intensity. Below the incident light intensity of 5 μJ/pulse, the refractive index effect is small, and transmittance at wavelength of 800 nm is almost constant. Therefore transmitted light

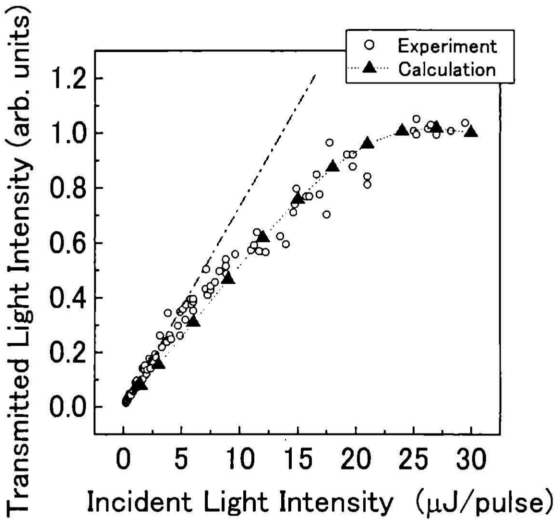

Fig. 5. Incident light intensity dependence of the transmitted light intensity of 1-D PC with PAT18 defect layer.

intensity increase linearly with the incident light intensity. Above the incident light intensity of 5 μJ/pulse, the refractive index effect causes the change of the refractive index at PAT18. In 1-D PC with a defect, the wavelength of defect modes shifts when the refractive index or the thickness of the defect layer changes. So the refractive index change in PAT18 causes the shift of the wavelength of defect mode. As a result, transmittance at wavelength of 800 nm goes down, and the increase of the transmitted light intensity is not linear. Therefore, optical limiting properties according to the transmittance change caused by nonlinear optical refractive index effect were observed.

Conclusion

We introduced conducting polymer in a dielectric multilayer structure as a defect in a 1-D PC. And we obtained optical limiting properties using nonlinear optical effect of conducting polymer.

References

1) S. John: Phys. Rev. Lett. 58 (1987) 2486.
2) E. Yablonovitch: Phys. Rev. Lett. 58 (1987) 2059.
3) J. S. Foresi, P. R. Villeneuve, J. Ferrera, E. R. Thoen, G. Steinmeyer, S. Fan, J. D. Joannopoulos, L. C. Kimerling, H. I. Smith and E. P. Ippen: Nature (London) 390 (1997) 143.
4) J. P. Dowling, M. Scalora, M. J. Bloemer and C. M. Bowden: J. Appl. Phys. 75 (1994) 1896.
5) V. I. Kopp, B. Fan, H. K. M. Vithana and A. Z. Genack: Opt. Lett. 23 (1998) 1707.
6) M. Ozaki, M. Kasano, D. Ganzke, W. Haase and K. Yoshino: Adv. Mater. 14 (2002) 306.
7) M. D. Tocci, M. J. Bloemer, M. Scalora, J. P. Dowling and C. M. Bowden: Appl. Phys. Lett. 66 (1995) 2324.
8) T. Hattori, N. Tsurumachi and H. Nakatsuka: J. Opt. Soc. Am. 14, (1997) 348.
9) Y. Dumeige, P. Vidakovic, S. Sauvage, I. Sgnes and J. A. Levenson: Appl. Phys. Lett. 78 (2001) 3021.